Radioisotope Applications

Jeffrey A. Mahn
Nuclear Engineer (Retired)
Albuquerque, NM USA
jamahn47@gmail.com

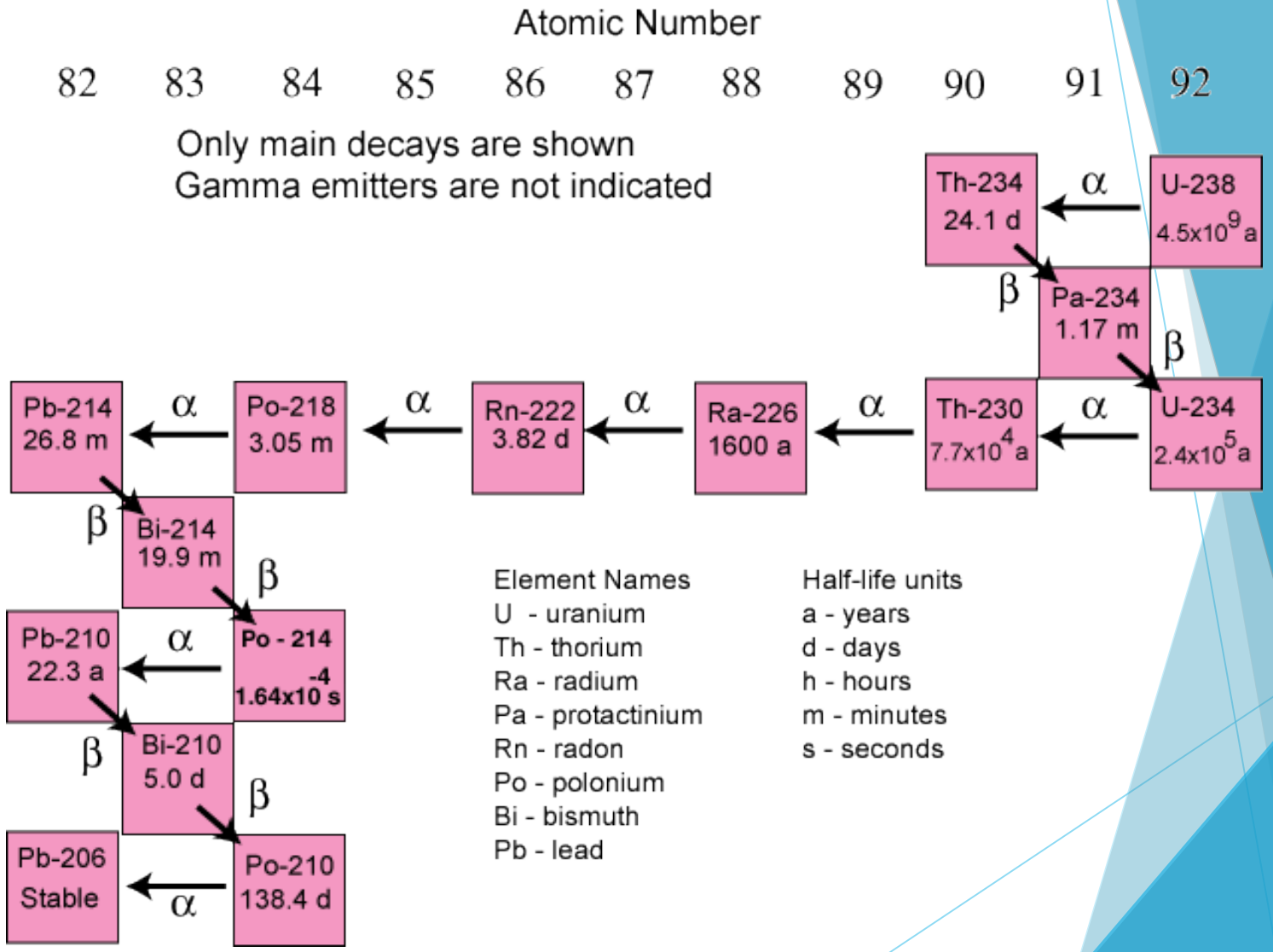
What Makes Some Atoms Radioactive?

- Two main factors that determine nuclear instability are neutron/proton ratio and total number of nucleons in nucleus
- Radioactive decay is process by which unstable atomic nuclei become more stable by emitting energy in the form of particles (α, β) and ionizing electromagnetic waves (γ-rays)

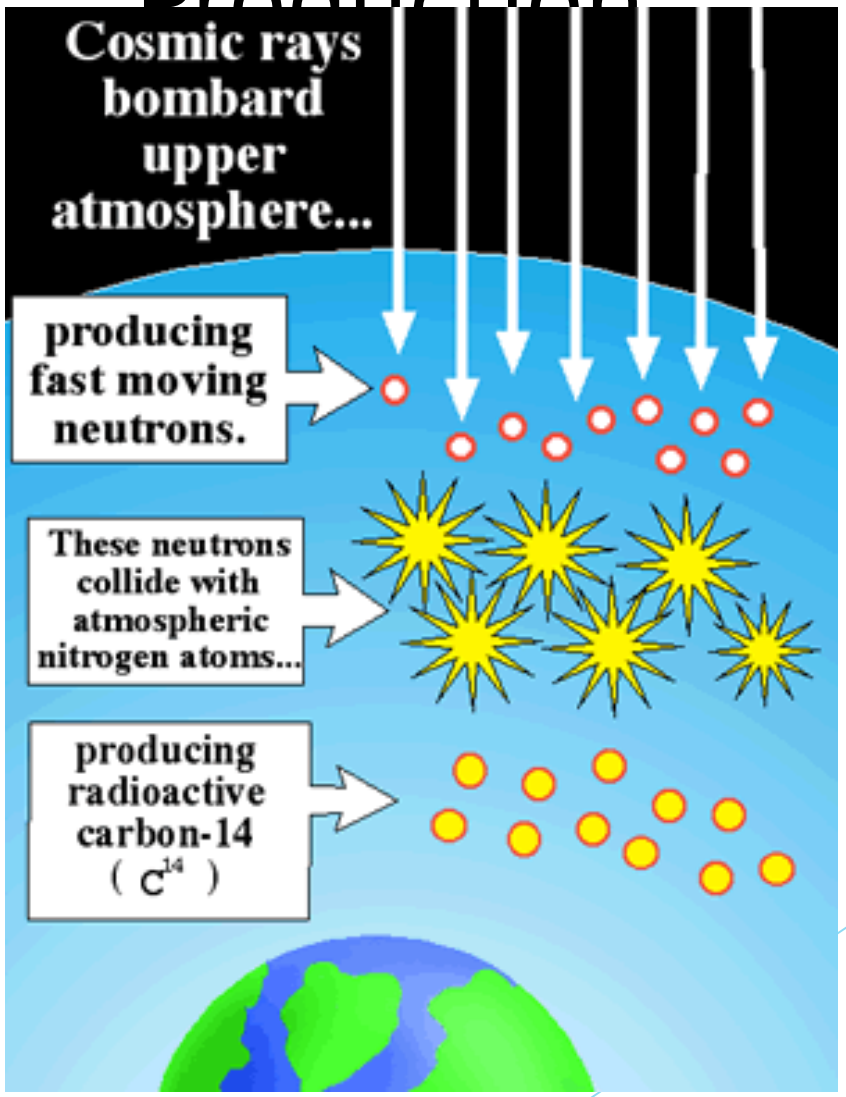
Sources of Radioisotopes

- Naturally occurring radionuclide decay chains (e.g., U-238, U-235, Th-232)
- Cosmic radiation interactions with Earth’s atmosphere (e.g., C-14, P-32, Cl-36)
- Nuclear reactors
- Particle accelerators
- Nuclear weapon tests

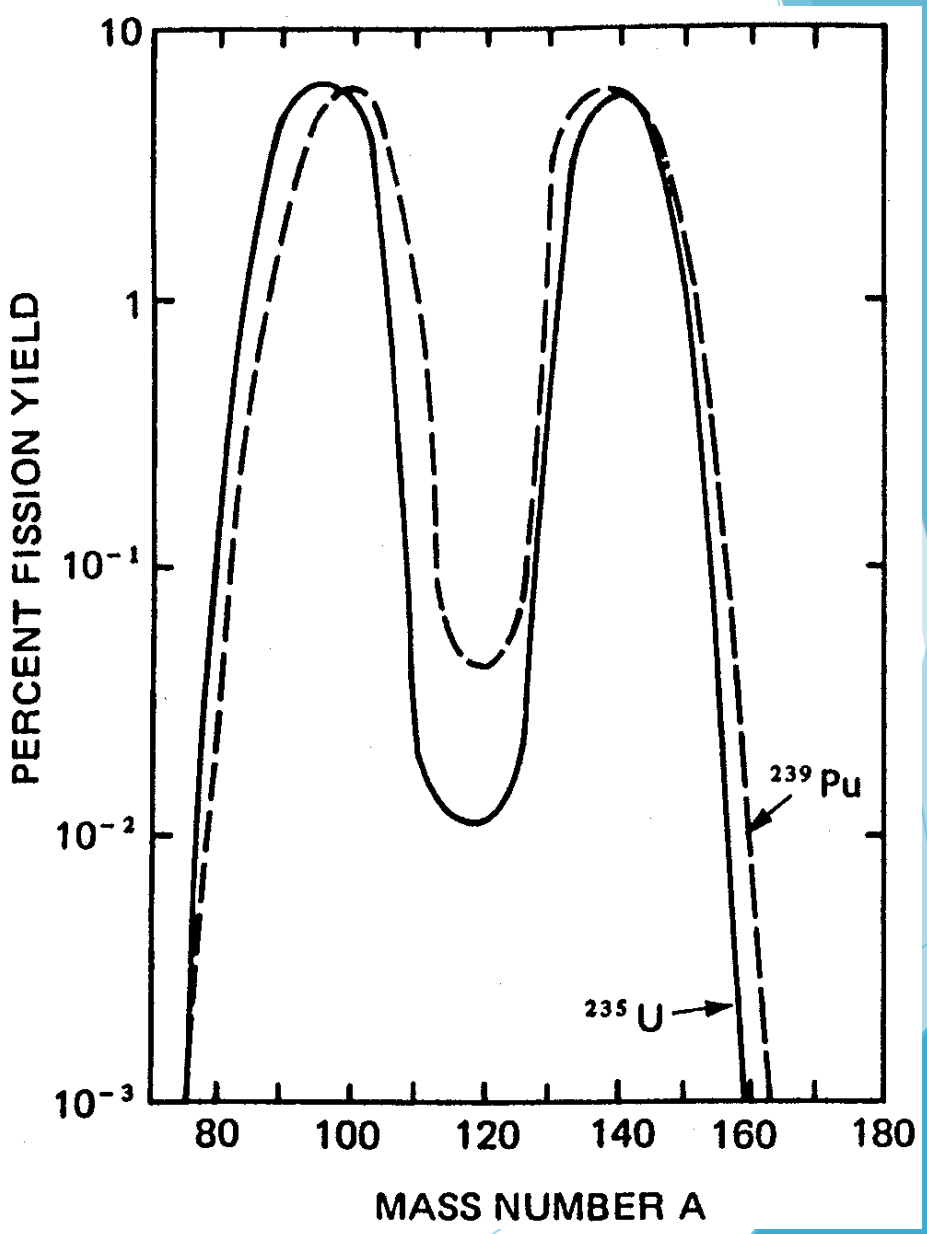
The Uranium-238 Decay Chain



Atmospheric Carbon-14 Production


Cosmic rays bombard upper atmosphere...
producing fast moving neutrons.
These neutrons collide with atmospheric nitrogen atoms...
producing radioactive carbon-14
(C^{14})

Fission Fragment Mass Distributions for U-235 and Pu-239



Particle Accelerator

Nuclear Weapon Tests

Radioisotope Applications

- Nuclear medicine – diagnostic and therapeutic radiology
- Modern industrial processes
  - radiography (imaging)
  - gauging applications (e.g., process material flow, density, or thickness control)
  - process material fill height detection/control
  - flow tracing and mixing measurements
  - sterilization of medical supplies, bulk commodities, and food products
  - non-destructive testing/evaluation (NDT/NDE) of materials (e.g., material analysis, flaw detection in metal cables, metal castings and welded joints)

Radioisotope Applications (cont.)

- Geologic tools for
  - radiometric dating of water, soil, rocks, and organic matter
  - measurement of soil density and water content
  - measurement of soil erosion rates and deposition
  - tracking of materials through complex geologic pathways
    (e.g., tracking of hazardous material movements in soils)
- Humanities – identification of forged treasures, artifacts, or artwork (neutron activation analysis "fingerprinting")

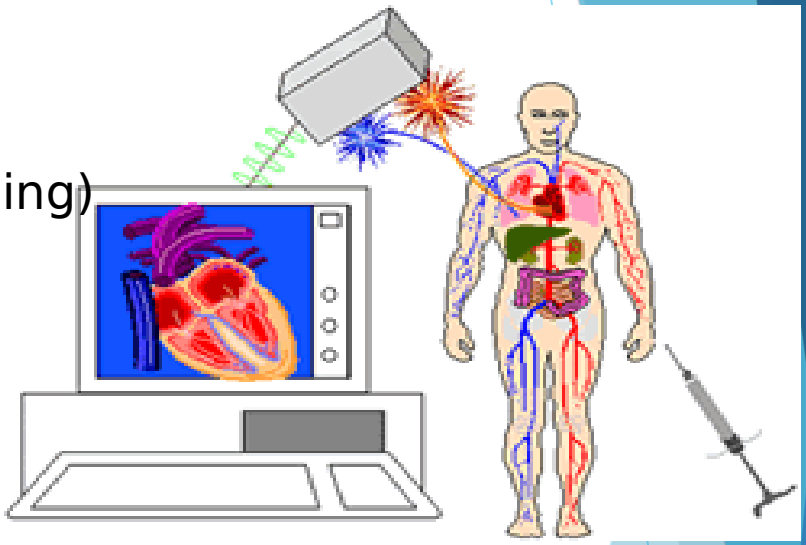
Radioisotope Applications (cont.)

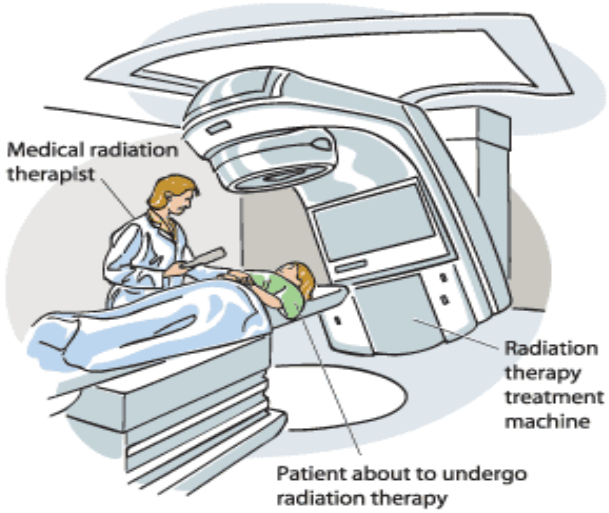
- Agricultural uses
  - research to develop hardier and more disease resistant crops and livestock by means of radiation-induced mutation breeding
  - study effectiveness of fertilizers with radioactive tracers
  - kill pests and parasites in food products
  - insect and rodent control utilizing radiation-induced sterilization techniques

Nuclear Medicine Applications

Types of Nuclear Medicine Doses

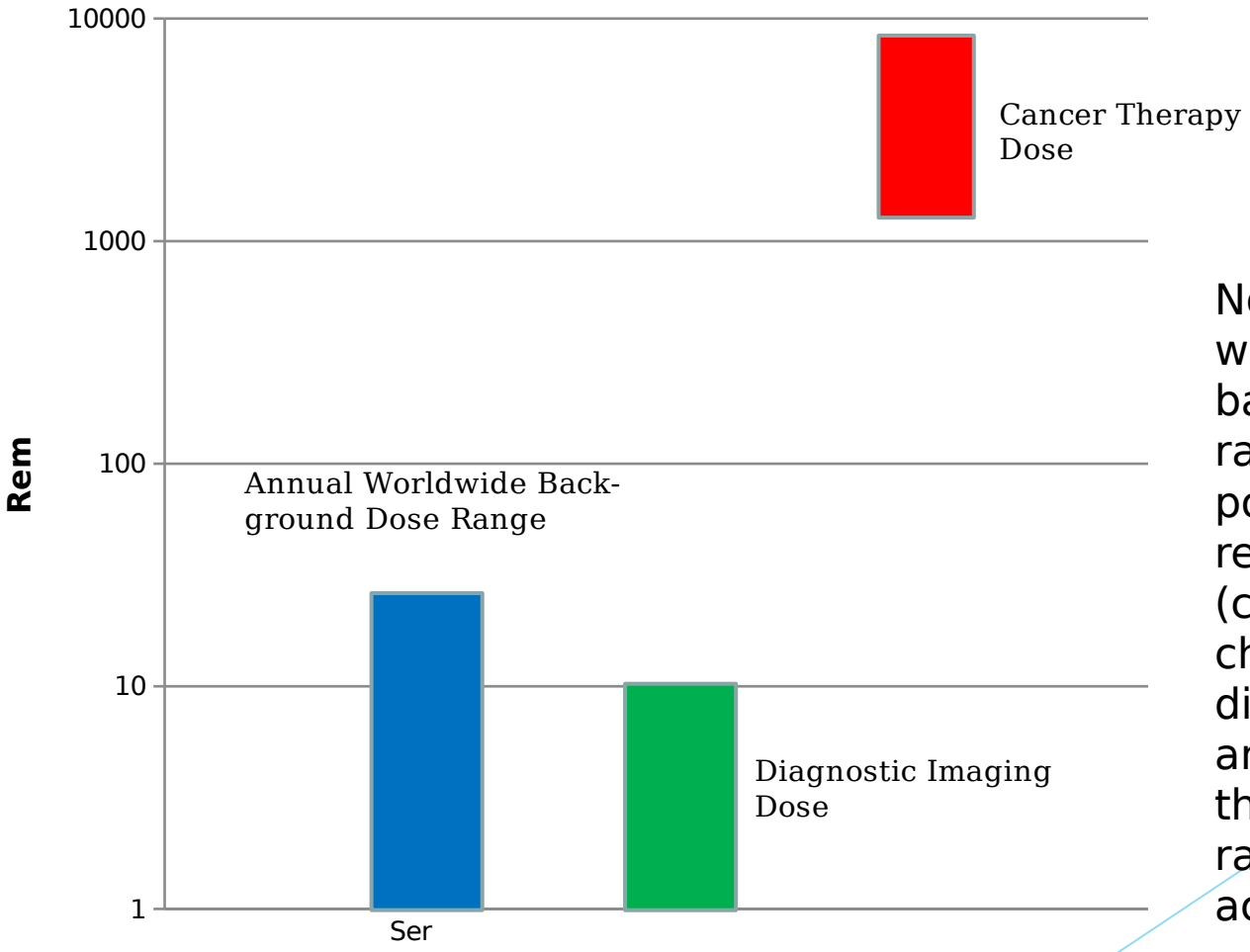
Diagnostic
Radiology (imaging)





Therapeutic Radiology
(cancer treatment)

Radiation Dose Ranges



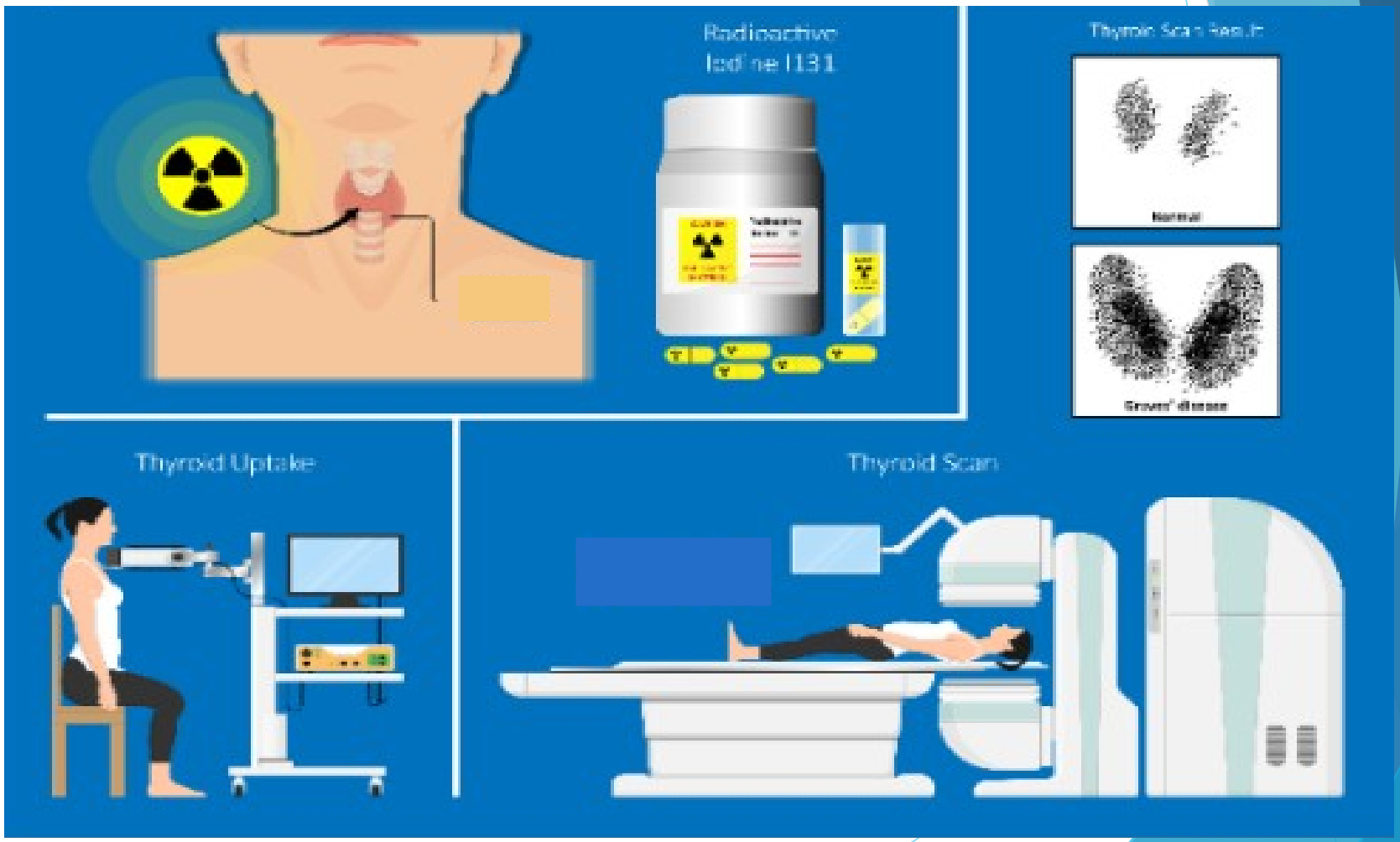
Note that worldwide background dose range (provided as point of reference) represents a (cumulative) chronic dose while diagnostic imaging and cancer therapy dose ranges are for acute doses

Technetium-99m

Most widely used diagnostic radioisotope worldwide

- Readily detected gamma-ray
- Decays to technetium-99 with 6-hour half-life
  - Tc-99m totally decayed in less than 3 days
- Tc-99 radiological half-life of 213,000 years (low activity)
  - Emits only beta particles, no gamma-rays
- Tc-99 biological half-life of 1 day (expelled from body quickly)
  - Poses little radiation burden on body

Thyroid Scan Using Radioactive Iodine



CT* Scan of Abdomen

* Computed Tomography (X-rays)

PET* Scan of Human Brain

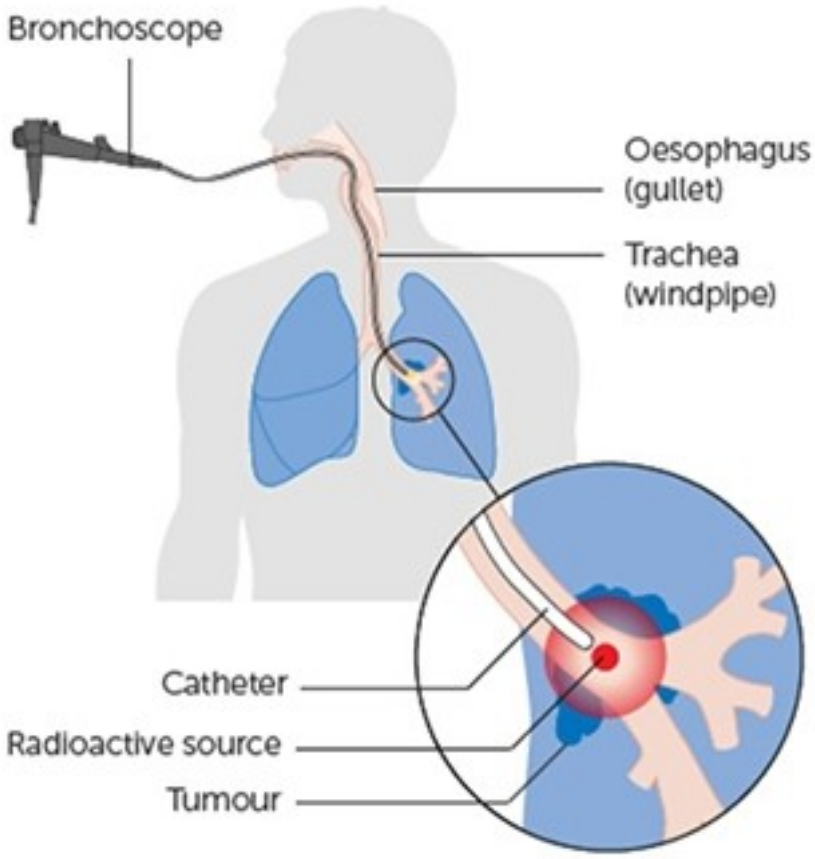
* Positron Emission Tomography

Types of Radiation Therapy

External beam radiotherapy – uses precisely focused external source of radiation to destroy tumors inside the body

Types of Radiation Therapy (cont.)

Brachytherapy – inserted catheter places radio-isotope directly at site of tumor



Types of Radiation Therapy (cont.)

Brachytherapy – radioactive seeds implanted at site of tumor

Types of Radiation Therapy (cont.)

Radiopharmaceutical Therapy

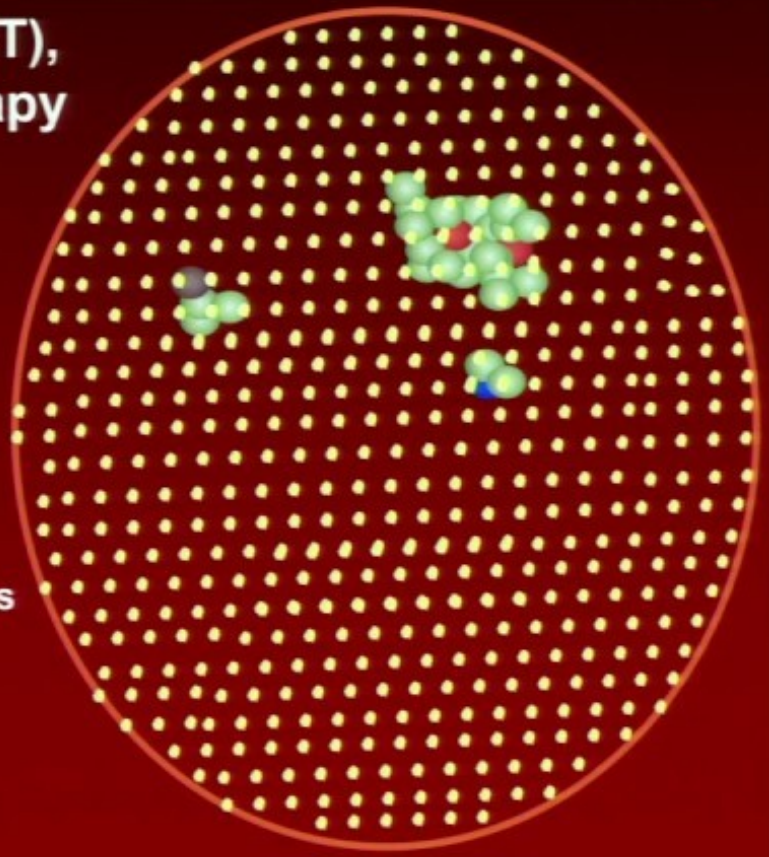
Molecular Radiotherapy (MRT),
Targeted Radionuclide Therapy
Radioimmunotherapy (RIT)

Agent distributes throughout body

Reacts with/binds to target cells

Cleared from non-target cells

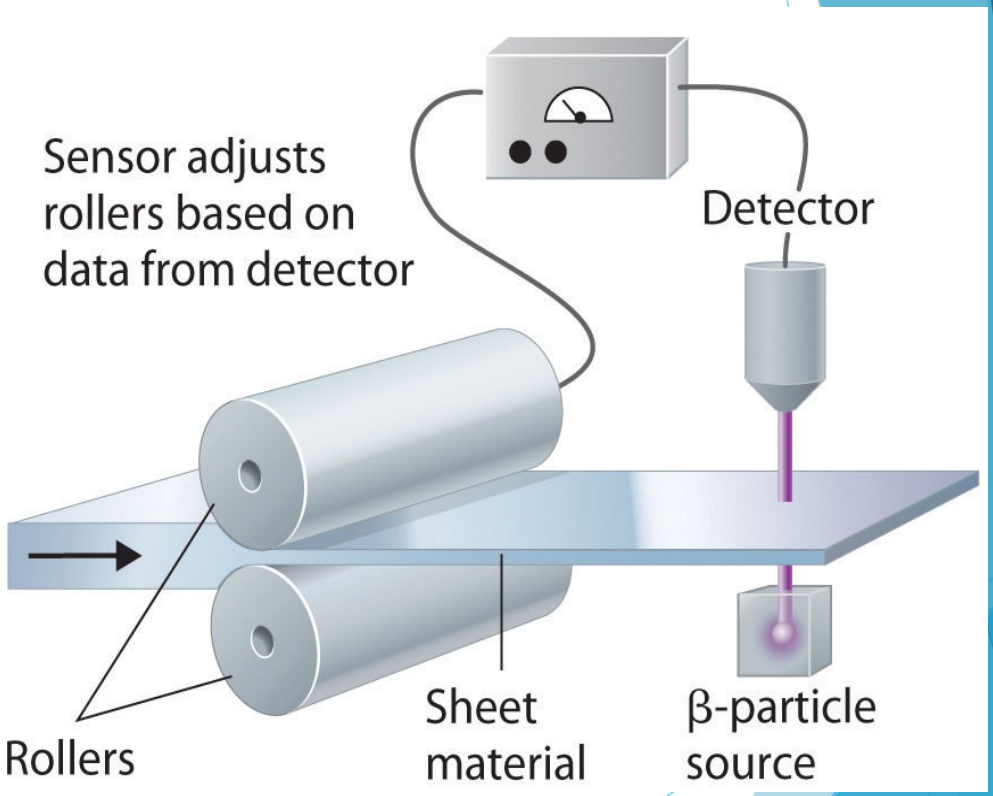
Prolonged exposure to target cells
gives larger radiation dose to target cells
than to normal cells



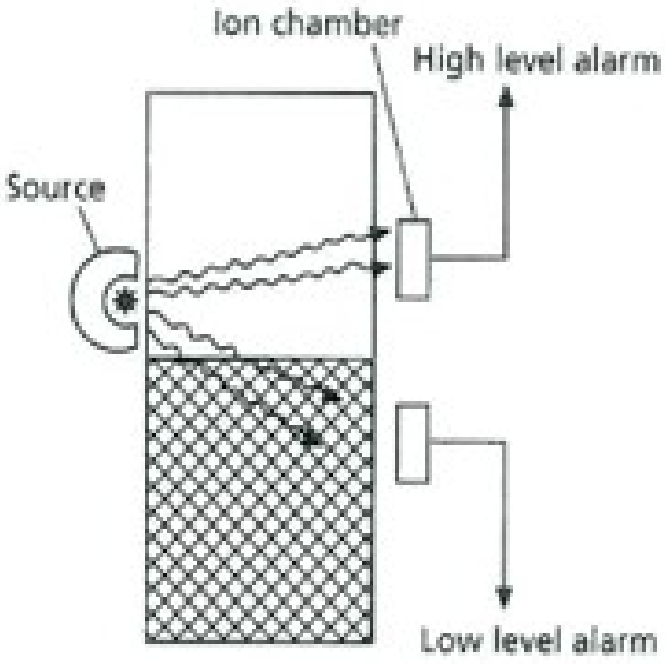
Industrial Applications

Radioisotope Gauging

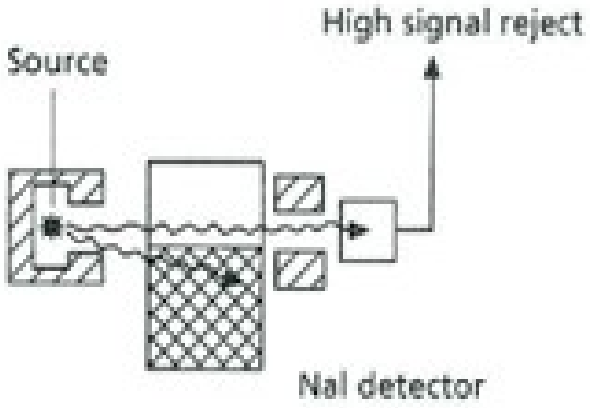
Material thickness process control



Radioisotope Gauging (cont.)

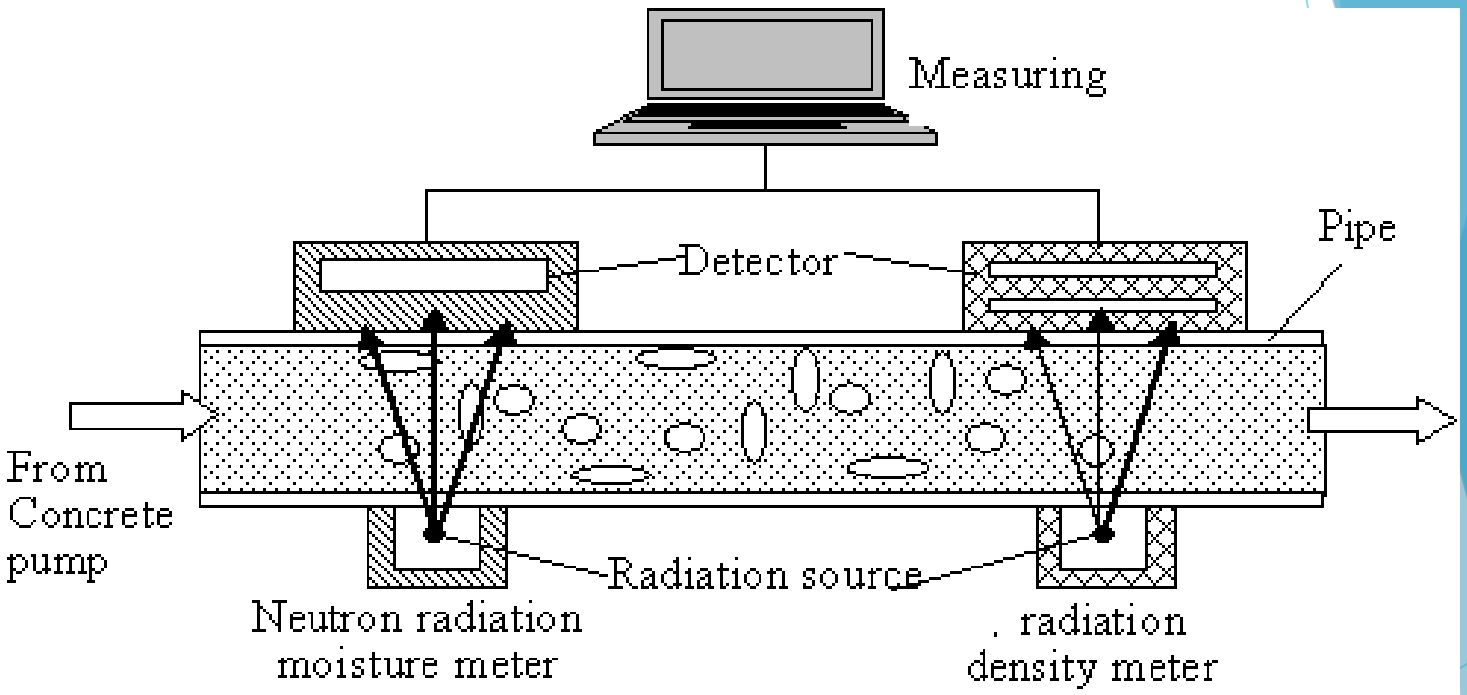


Material level process control



Package contents monitoring

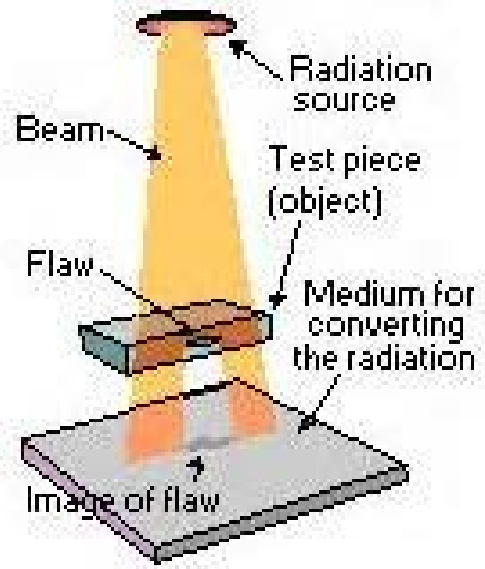
Radioisotope Gauging (cont.)

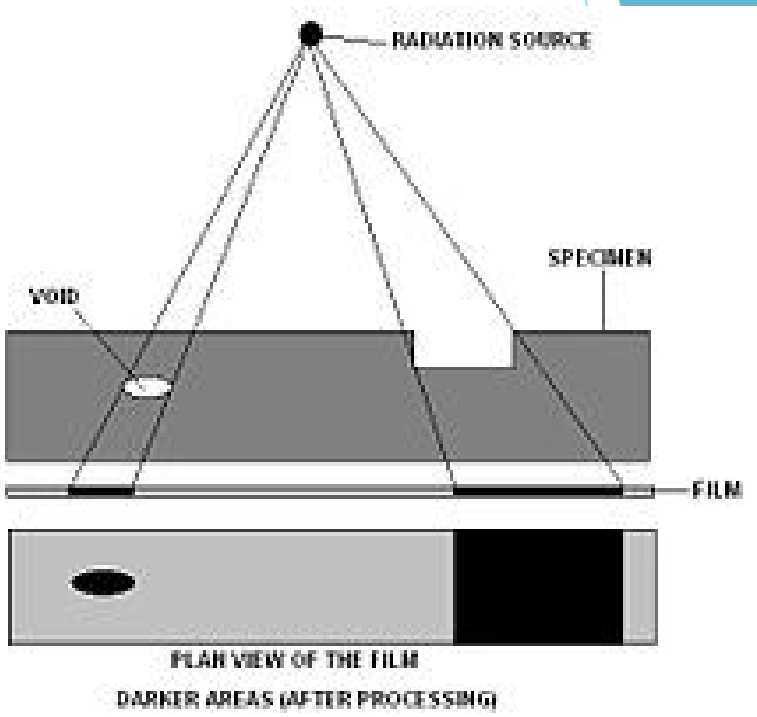


Process material flow measurement for moisture and void content

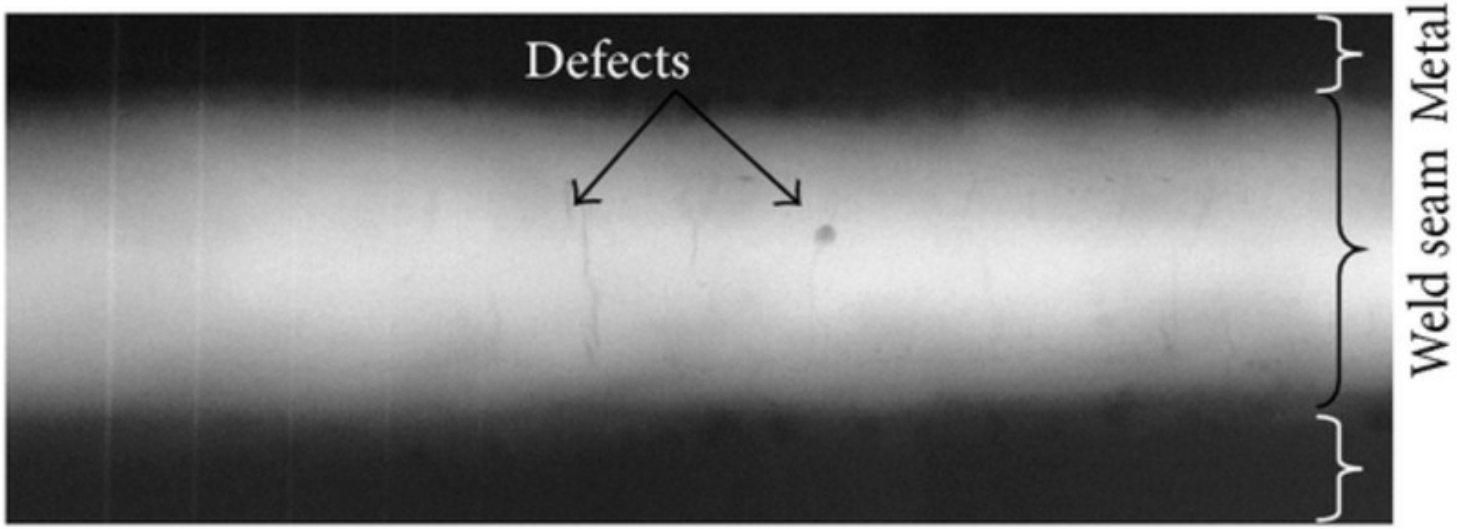
Non-destructive Examination (Radiography)

Material physical characterization



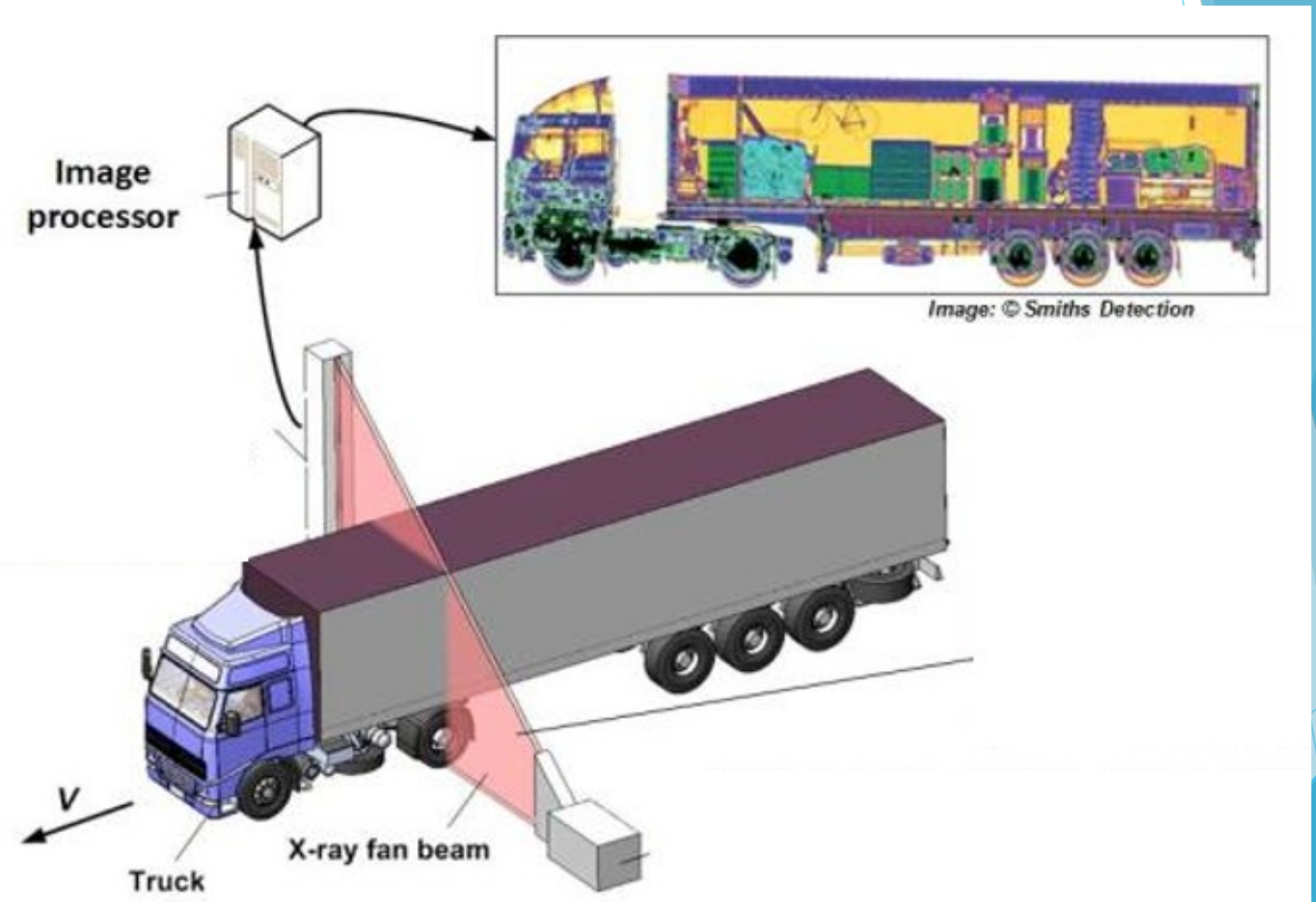


Non-destructive Examination (cont.)

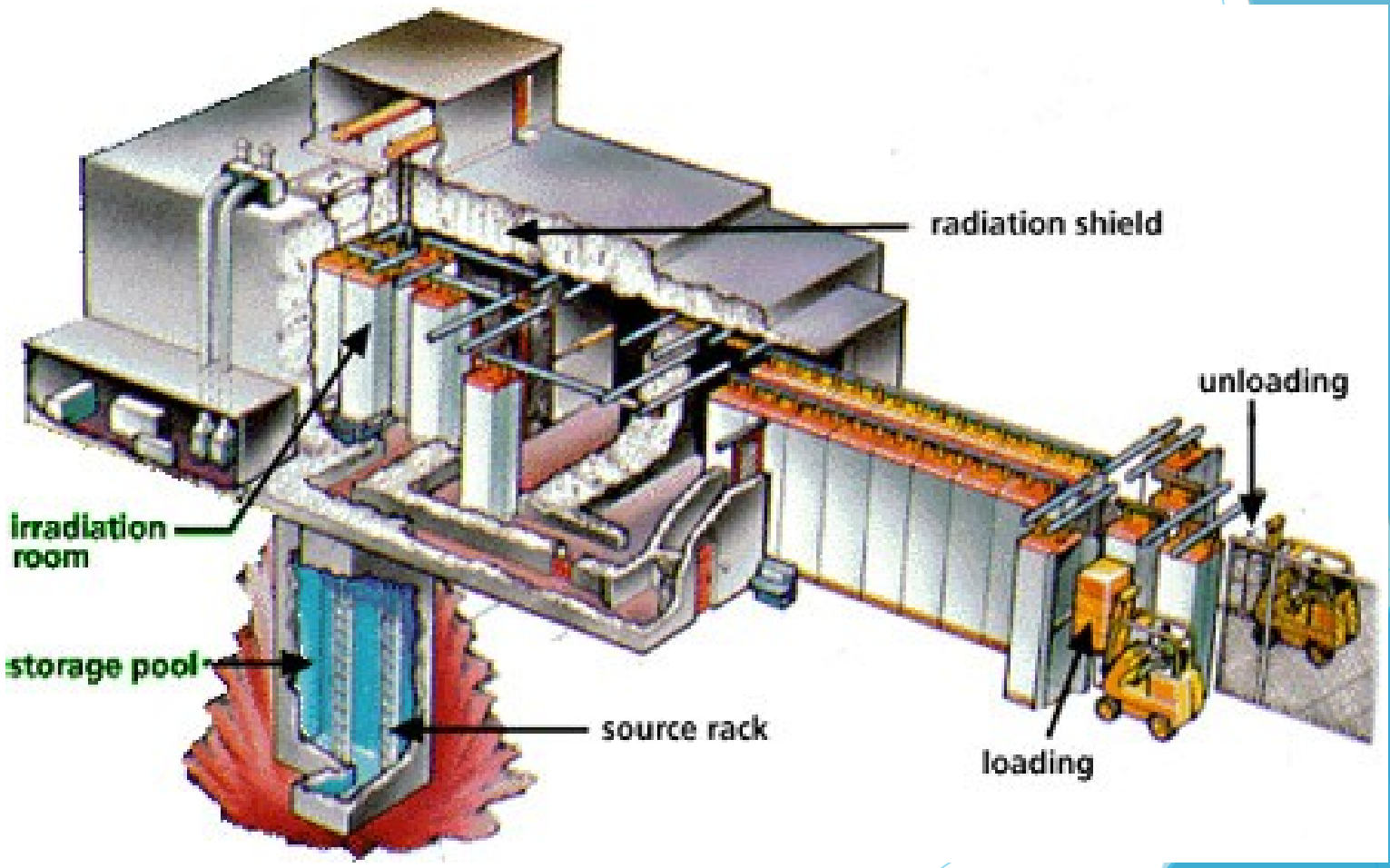


Weld radiographic image

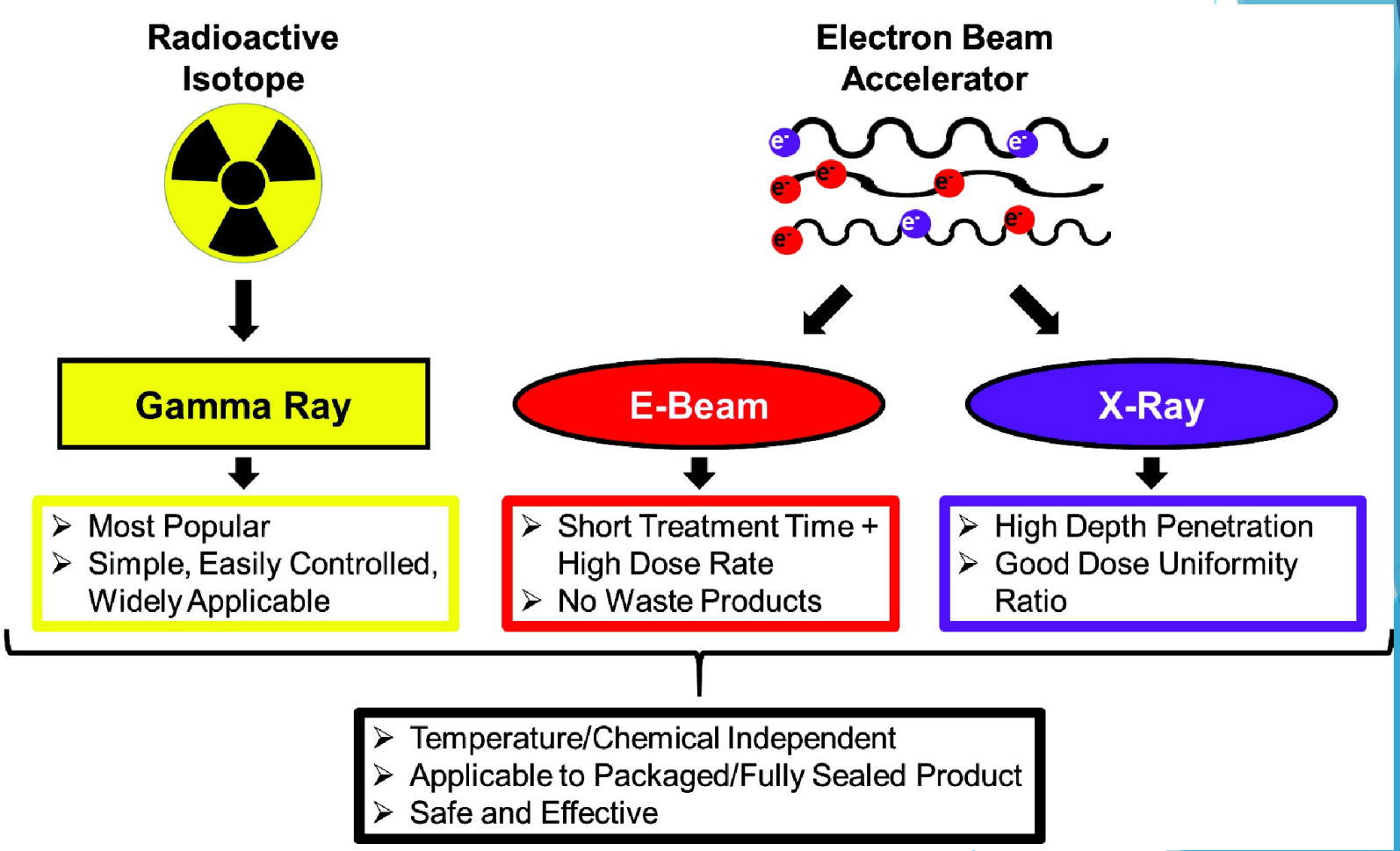
Cargo Scanning



Radiation Sterilization



Radiation Sterilization (cont.)



Food Irradiation

By killing microbes and bacteria in food products, irradiation keeps food from spoiling.

Environmental Applications

Environmental Applications

- Studies of the atmosphere
  - following atmospheric dispersion, transport, and mixing processes
  - identifying sources and sinks of atmospheric gases
  - measuring deposition of atmospheric constituents on bodies of land and water
- Studies of Earth's surface waters
  - measuring replenishment of groundwater resources
  - monitoring interactions between surface and groundwaters
  - measuring sedimentation rates in lakes and reservoirs
  - measuring water aeration
  - groundwater radiometric dating

Environmental Applications (cont.)

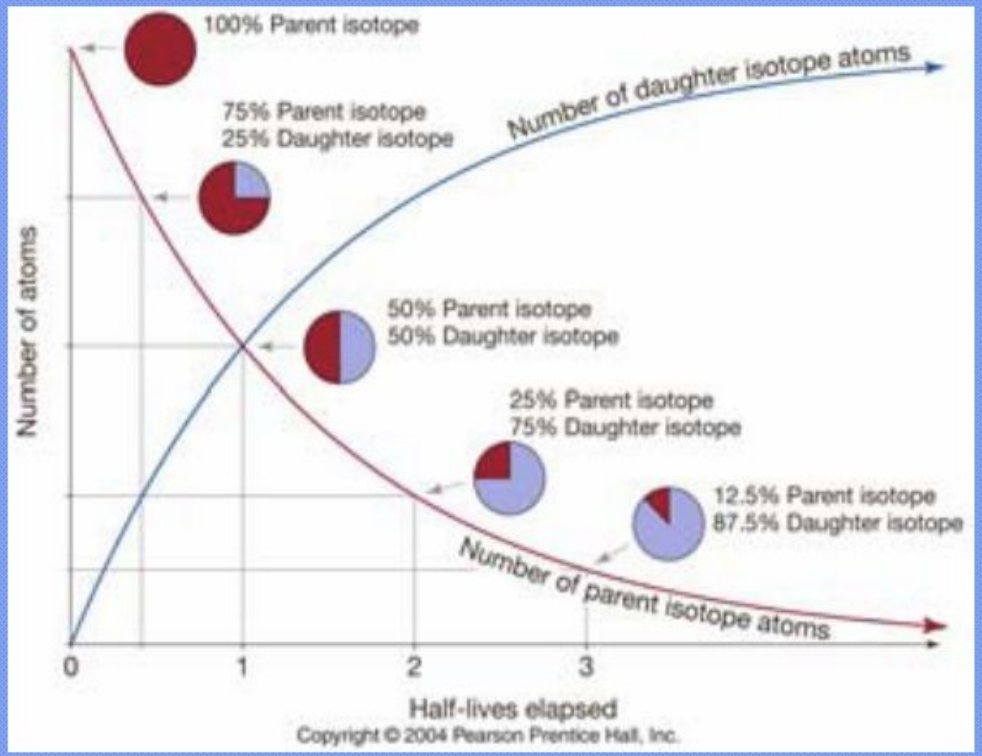
- Studies of Earth's crust and upper mantle
  - measuring soil erosion
  - mineral exploration
  - earthquake monitoring
  - radiometric dating of rocks and minerals
  - radiometric dating of lake sediments
- Ocean studies
  - following ocean circulation and mixing processes
  - measurement of past variations in sea level
  - measurement of CO_2 exchange with the atmosphere
  - radiometric dating of ocean sediments

Radiometric Dating

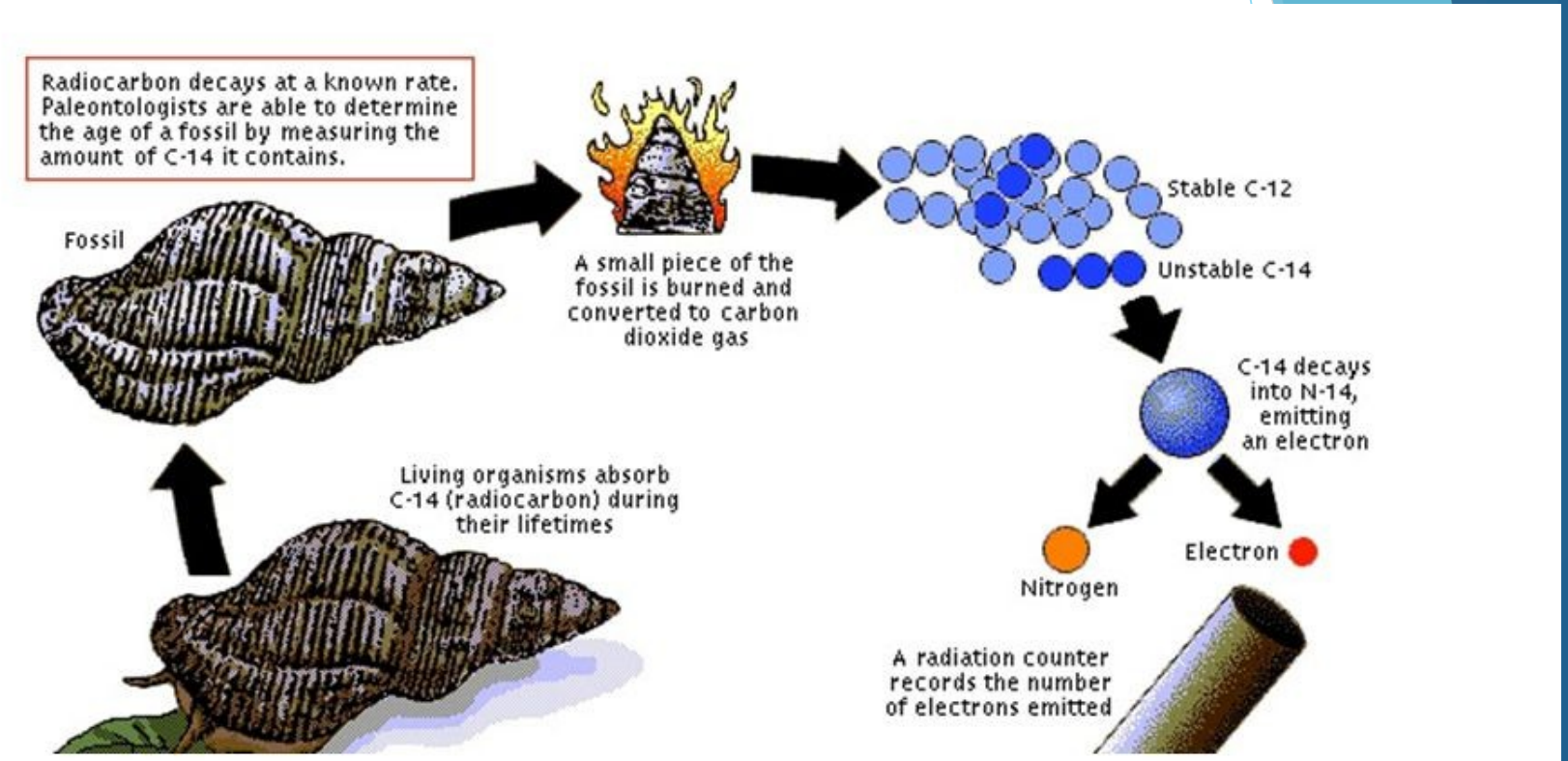
Isotope		Half-life of parent (years)	Useful range (years)
Parent	Daughter		
Carbon 14	Nitrogen 14	5,730	100 - 30,000
Potassium 40	Argon 40	1.3 billion	100,000 - 4.5 billion
Rubidium 87	Strontium 87	47 billion	10 million - 4.5 billion
Uranium 238 Uranium 235	Lead 206 Lead 207	4.5 billion 710 million	10 million - 4.6 billion

Radiometric Dating (cont.)

The age of sample is calculated based on the amount of remaining radioactive isotopes it contains.

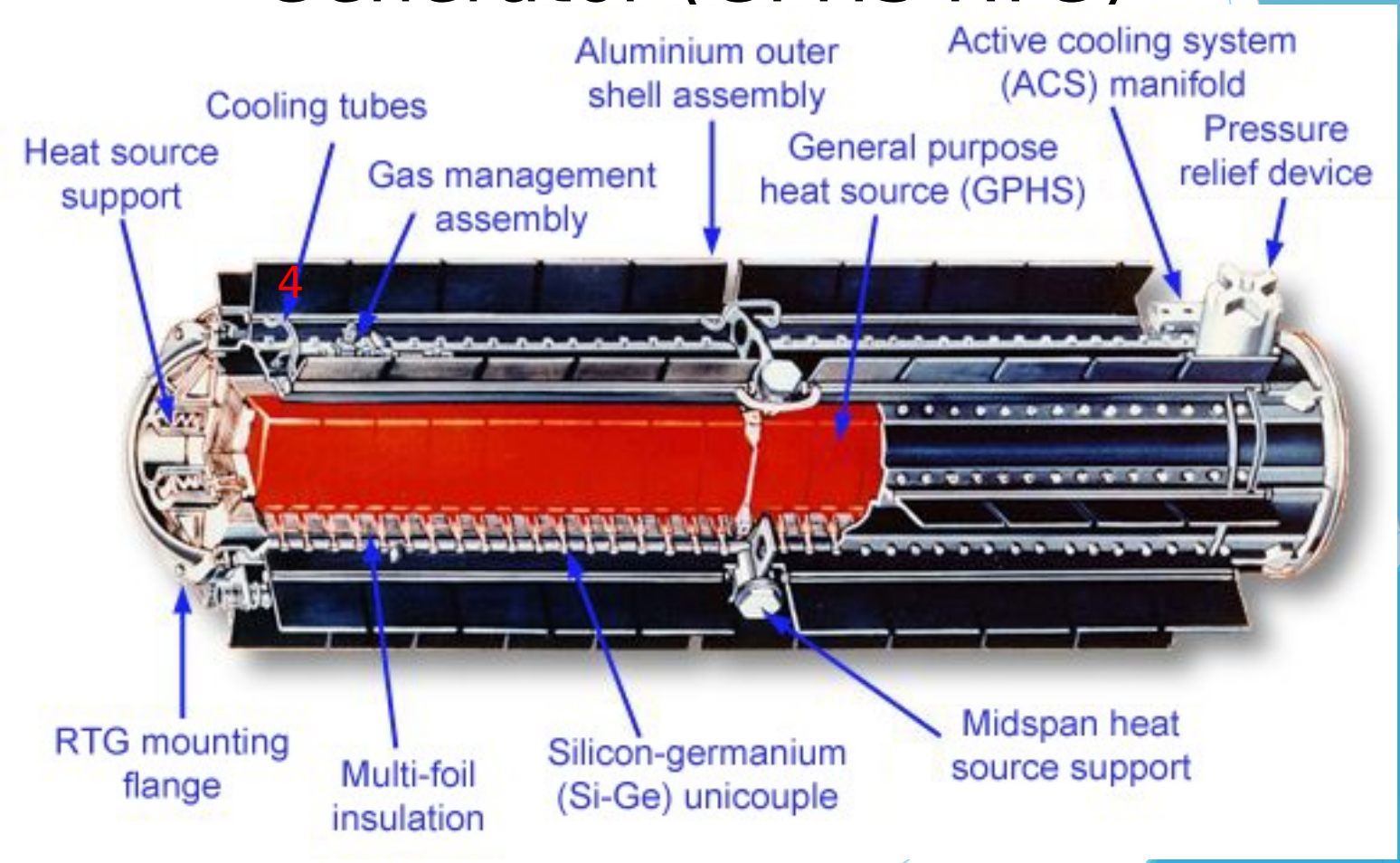


Radiometric Dating (cont.)

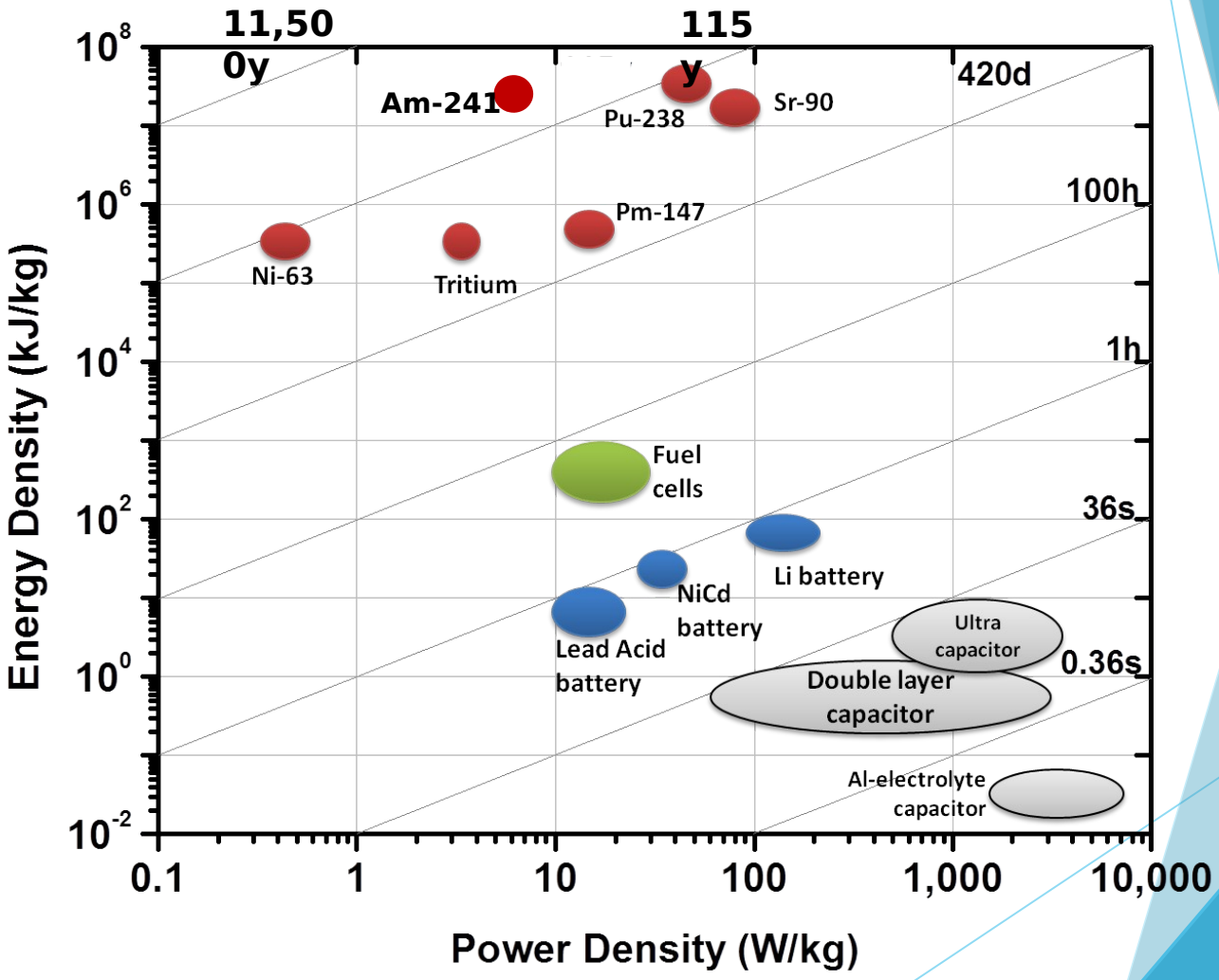

Radiocarbon decays at a known rate. Paleontologists are able to determine the age of a fossil by measuring the amount of C-14 it contains.
Fossil
A small piece of the fossil is burned and converted to carbon dioxide gas
Stable C-12
Unstable C-14
C-14 decays into N-14, emitting an electron
Electron
Nitrogen
A radiation counter records the number of electrons emitted
Living organisms absorb C-14 (radiocarbon) during their lifetimes

Space Applications

General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS RTG)



Nuclear Batteries

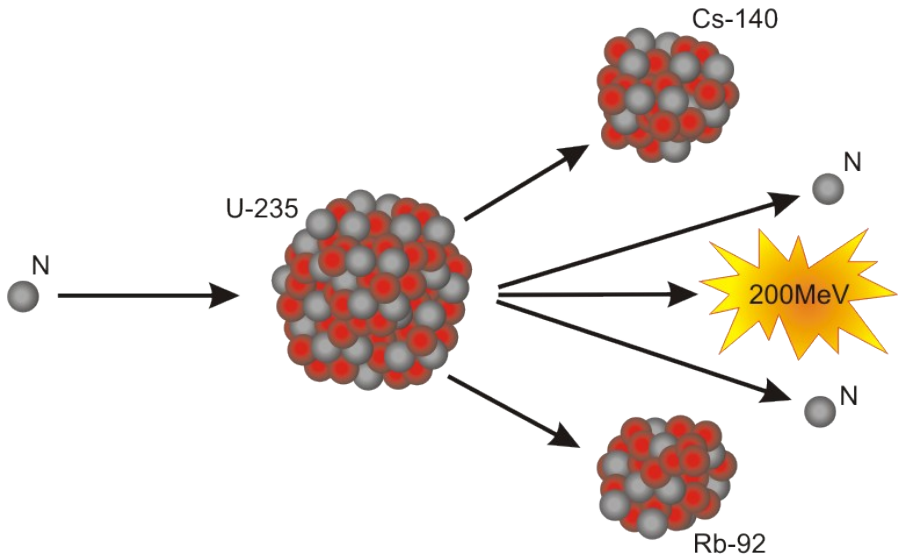


Supplemental Slides

Significance of Radioisotopes to Nuclear Science

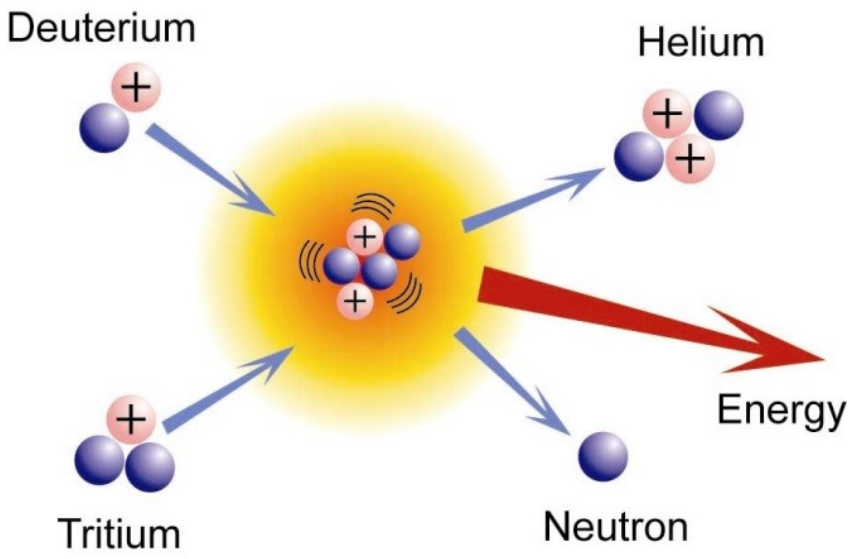
- In strictest sense, nuclear science is study of nuclear changes in matter; i.e., changes involving atomic nuclei
- Nuclear changes occur in four processes that involve radioactive isotopes
  - Fission
  - Fusion
  - Radioactive decay
  - Nuclear bombardment

Fission



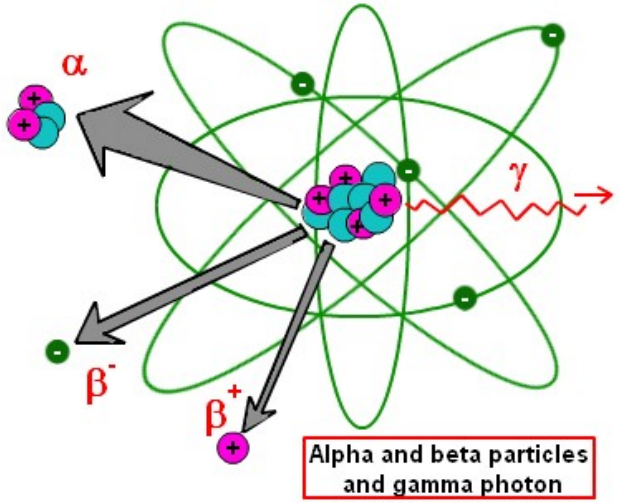
Fission enables us to generate abundant, affordable, and reliable electricity from uranium and plutonium radioisotopes.

Fusion



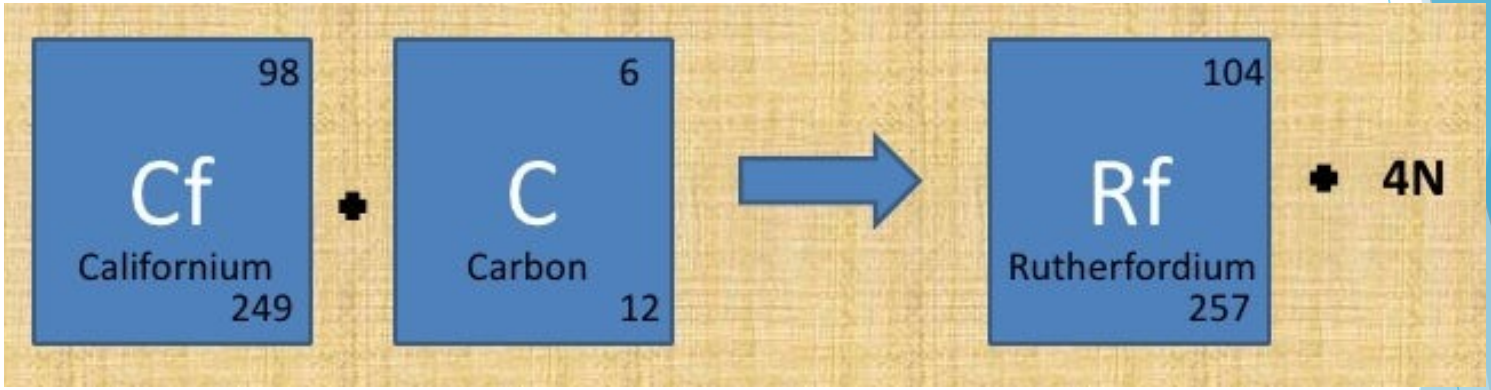
Fusion, using a radioisotope of hydrogen, may be an energy source of the future.

Radioactive Decay



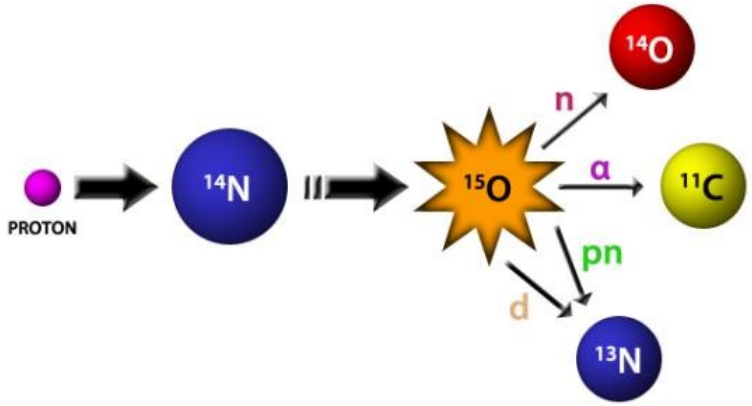
The properties of radioisotopes facilitate solutions to a variety of science-based challenges in numerous fields of human endeavor. Radioisotopes can provide information about conditions that we would otherwise be unable to discern.

Nuclear Bombardment – Creation of Artificial Elements



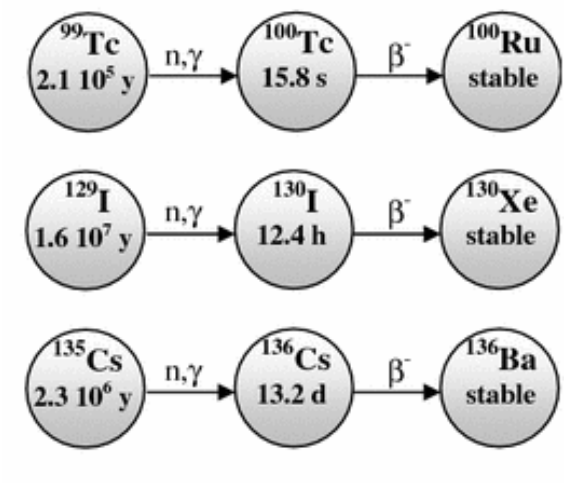
Some useful radioisotopes can be created when two nuclei are propelled together. Others, as shown above, are created purely for purposes of research.

Nuclear Bombardment – Creation of Radioisotopes



Some useful radioisotopes can be created when a small particle (e.g., a proton, deuteron, or alpha particle) is propelled at a nucleus.

Nuclear Bombardment – Transmuting Long-lived Fission Products



Some long-lived radioisotopes can be converted to shorter-lived radioisotopes using accelerator driven systems or fast reactors.

Nuclear Batteries